# Abilities and Limitations of Eyewitnesses Assessed on Atmospheric Entries of Meteoroids and Artificial Satellites

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**Abstract**: Observers' reactions to known phenomena with multiple witnesses provide a good test of their ability to accurately describe unfamiliar, brief, and unexpected events. We analyzed statistically about 300 accounts of 7 atmospheric entries of meteoroids and satellites reported to the French police during 1980-2009 and quantitatively estimated the reliability of witnesses for a dozen spatial, temporal, and structural characteristics. On a scale of 0 to 1, the reliability is practically zero for metric data and direction of motion, which cannot be determined in general from sensory data, and varies from 0.5 to almost 1 for directly perceptible characteristics. Witness reliability is not a simple concept as it is highly dependent on the characteristics being studied, the expected accuracy, and methodological constraints. It is also not a static notion because it can be improved by helping the witnesses provide objective information (e.g. angular data instead of metric data).

**Keywords**: Measurement of witness reliability, Psychology of perception, Intersubjectivity, Misinterpretation, Statistical methods, Lognormal distribution, Time estimation, Distance estimation, Color vision, UAP, Police reports

## Introduction

To what extent are human observers able to accurately describe an unfamiliar phenomenon to which they are unexpectedly and relatively briefly exposed? To answer this question, one must be able to compare what the observers perceived, or more precisely what they say they perceived, with the known characteristics of the phenomenon. One possible approach, which has the advantage of being based on the vast resources of experimental psychology, is to present the subject with artificial stimuli controlled by the experimenter in the laboratory (e.g.[1]). Another approach, less precise but closer to natural conditions, consists in analyzing how observers describe known natural or man-made phenomena that they happen to witness. We will follow here this second approach, based on atmospheric entries of meteoroids or artificial satellites (payloads and rockets), already illustrated by a few previous studies.[2,3,4,5] These bodies burning in the atmosphere are visible from the ground as more or less spectacular moving lights depending on their speed and size. Observers of atmospheric entries, whether they identify them as such or not, are in conditions similar to those of other rare and less easily identifiable phenomena known as UFOs or UAPs, and so provide reference information for the assessment of UAP reports.

The available reports of atmospheric entries provide numerous pieces of information on the observed phenomena and their conditions of observation. First, we will investigate how observers report or fail to report various characteristics of these events, whether spatiotemporal (like time,

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[1] Jimenez, "Les phénomènes aérospatiaux non-identifiés et la psychologie de la perception."

[2] Hartmann, "Process of perception, conception, and reporting."

[3] Drake, "On the abilities and limitations of witnesses of UFO's and similar phenomena."

[4] Jimenez, *Témoignage d'ovni et psychologie de la perception*. This study is based on police reports of 18 atmospheric entries from the period 1974-1990, of which two (#1017 and #1159, see below) are also included in our sample.

[5] Jimenez, *La psychologie de la perception*.

duration, height, distance and direction) or intrinsic (like structure and colors). Second, we will evaluate how perceived characteristics differ from the actual characteristics of the phenomena as known from the scientific literature or derived from the reports themselves. Then, defining the reliability for a given characteristics as the ratio of the number of correct descriptions to the total number of descriptions, we will propose practical methods for quantitatively measuring the reliability of eyewitnesses for various characteristics. We will also provide some brief comparisons with previous studies.

### Selection of Reports

Before studying their content, let's give an overview of the observers' accounts. They were extracted from a set of reports gathered by GEIPAN, the UAP study group of the French National Center for Space Studies (CNES). In the period 1980-2009 covered by the present study, more than 2200 reports were received by GEIPAN on about 1700 UAP events involving more than 5000 witnesses. The events of interest for the present study are atmospheric entries with multiple witnesses. We found 215 atmospheric entries, but only 16 with 10 observers or more. However, three-fourths of the corresponding reports were generated by only one event, a launcher re-entry that occurred on November 5, 1990. This massive event would require a specific analysis, so it was not included in this study. We drew at random 7 of the 15 other events for detailed analysis.

Table 1 summarizes the main features of the 7 selected atmospheric entries. Six of them were interpreted as meteoroids and one as an artificial satellite. They generated 116 reports based on the observations of more than 350 witnesses (Nt). The majority (83%) of recorded testimonies (Nr) came from the *Gendarmerie Nationale*, one of the two national police forces in France in charge of rural and suburban areas. The other testimonies came from the Civil Aviation agency (7%), the urban police (1%), and directly from observers (9%). The difference between recorded (Nr) and detailed (Nd) testimonies results from our exclusion of the observers who did not provide their own description but merely confirmed another observer's statements; this means that only explicit statements were considered. We also removed from Nd a report that was not likely to describe an atmospheric entry (see next section), thus obtaining the testimonies actually used (Nu = 283).

Table 1. Main features of atmospheric entries studied

| Event | Date | Time | Nt | Nr | Nd | Nu | Ndp | Nco | Object |
|---|---|---|---|---|---|---|---|---|---|
| #1017 | 11.11.1980 | 18:37 | 144 | 125 | 117 | 117 | 25 | 70 | meteoroid |
| #1159 | 06.06.1983 | 22:57 | 52 | 45 | 35 | 35 | 11 | 22 | meteoroid |
| #1461 | 11.28.1991 | 22:28 | 30 | 26 | 26 | 26 | 7 | 19 | meteoroid |
| #1667 | 08.01.1996 | 21:24 | 75 | 67 | 65 | 64 | 11 | 49 | meteoroid |
| #1769 | 02.01.1999 | 07:15 | 13 | 13 | 11 | 11 | 3 | 10 | meteoroid |
| #2290 | 09.25.2008 | 22:55 | 23 | 16 | 16 | 16 | 12 | 16 | satellite |
| #2378 | 01.17.2009 | 18:47 | 19 | 14 | 14 | 14 | 9 | 14 | meteoroid |
| Total | | | 356 | 306 | 284 | 283 | | 200 | |

*Event*, event identifier. *Date*, date of the event. *Time*, approximate legal time of the event (see section Time for details). *Nt*, number of known observers. *Nr*, number of observers met by investigators. *Nd*, number of detailed testimonies (observers who only confirmed another witness were excluded). *Nu*, number of usable testimonies (one sighting unrelated to event #1667 was excluded). *Ndp*, number of *départements* from which the event was reported. *Nco*, number of communes with observers. *Object*, all events resulted from meteoroids except #2290 (Russian launcher).

Table 1 shows that the phenomena were observed during night-time hours in geographical areas whose size can be estimated by the number of *départements* where witnesses were located (*départements* are administrative units of approximately 6000 square km, corresponding to a circular area ca. 90 km in diameter). These areas are well-correlated with the number of observers and the number of communes where the observers were located (communes are the smallest administrative units, one tenth the diameter of a *département*). Depending on the event, the area of visibility included from 3 to 25 *départements* (roughly 3% to 27% of metropolitan France), which indicates that the visibility of the phenomena was not at all equivalent, with many factors like brightness, duration, cloud cover, time of the day, etc. contributing to the visibility. Other aspects of the events are described in the following sections devoted to their various characteristics. Unless otherwise stated, all statistics (numbers and percentages rounded to the nearest integer) are given with respect to the 283 useful testimonies.

**Anomalous Motion and Confusion**

Although witnesses usually reported a light or set of lights moving at constant speed across the sky, in eight accounts the light was perceived as stationary during all or part of the observation. This can occur if the object is following a path directed exactly toward the witness, but this should be rare and reports suggest other explanations, as follows.

Four testimonies that do not show inconsistency in duration are likely the result of misperceptions. The witness' own movement in a car in the first case, the brevity of an "apparently stationary" light seen for only 2 seconds in the second case, and the alleged "stabilization" of a moving light before it goes out in the third one, are consistent with this hypothesis. The fourth example will be discussed in the second-to-last section.

Four other testimonies of stationary phenomena also present inconsistencies in time and/or duration. In event #1667, a witness saw the meteoroid fall and then, along with his friend, a white light seemingly motionless on the ground for 20 min – a tractor at work in a field according to the police investigation. The confusion of two independent phenomena is reflected here by discrepancies in motion and duration. About an hour after the most probable time of event #1017, two witnesses reported an intermittent blue light in the sky and a few seconds later a red sphere motionless for 2 min. The blue light is consistent with other descriptions of meteoroid #1017, which raises the possibility that the red sphere was something else, the moon for example; the witnesses deny this interpretation but they do not indicate the direction of observation which prevents a verification. In the last testimony, 80 min after the fall of meteoroid #1667, three lights forming a triangle were seen stationary for 30 min. In this report at least three elements (immobility, time, and duration) are inconsistent with the meteoroid assumption. For this reason this account was removed from our final sample (hence the difference between Nd and Nu) which avoids mixing witness errors (the signal we want to study) with erroneous selection by us of irrelevant phenomena (noise).

**Deviation from the Actual Date and Time**

All observers provide the date of the event. In 5 cases (2%) this date is wrong by one day (the next day is given), although the day of the week is correct in one of these reports. Time is the second characteristic most frequently reported by witnesses (in 95% of usable testimonies). However, the variable of interest for the present study is not time in itself but the difference between the time given by the observer and the actual time of the event. For some events the actual time is known approximately from *a priori* reliable observers (see below) but this is not always the case, so we preferred to take the mean of all the times reported for a given event as a reference.

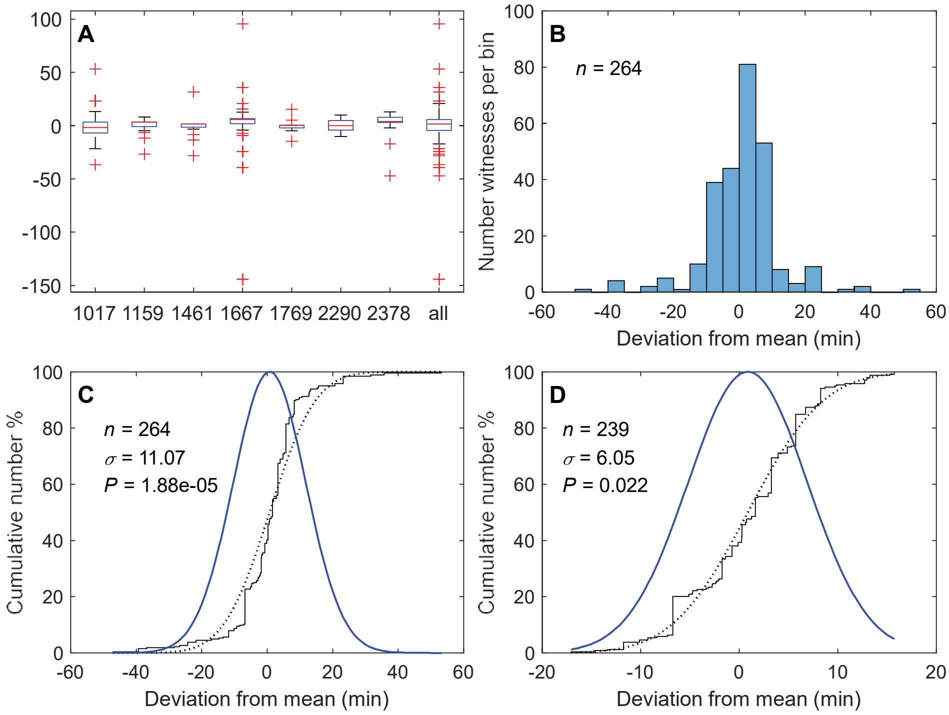

Figure 1. Deviation of observation times from the mean time of each event. **A**. Boxplots of the 7 events (from #1017 to #2378). The rightmost boxplot is for all events together (n = 264). The boxes extend from the lower quartile (25% of the data are below this point) to the upper quartile (75% of the data are below this point) with the medians (red line with half values smaller or greater) in between. The whiskers extend to the most extreme data values within 1.5 × IQR (interquartile range from lower to upper quartiles). Outliers (red crosses) are deviations beyond the end of the upper whiskers. **B**. Histogram of deviations with bin width 5 min. Three outliers with deviations -144, -144 and 96 min. not shown. **C**. Empirical cumulative distribution function (CDF) of deviations less than ±60 min. (solid black staircase); all deviations are shown along the x-axis as stepwise jumps of height 1/n, giving a complete and undistorted view of the original data. Empirical CDF is fitted to a normal distribution (smooth dotted curve) of mean μ (close to 0) and standard deviation σ; fit is rejected at level 1% (P-value < $10^{-4}$). Fitted normal probability density function (PDF) shown as smooth blue curve. **D**. Empirical CDF of deviations less than 20 min. from the mean (staircase) fitted to a normal distribution (dotted CDF and solid blue PDF curves); fit is not rejected at level 1% (P-value = 0.022).

Different views of the deviations from the mean time are displayed in Figure 1. The deviations are shown as so-called boxplots in Figure 1A, first separately for each event from left to right, then for all events together. Most deviations are relatively small and similar in all events, as shown by the heights of the central rectangles that contain half of the deviations in each event, although relatively large deviations are found (from 3 to 9 per event drawn as red crosses). Figure 1B shows all deviations together as a histogram whose bell shape is consistent with the idea that time deviations follow a Gaussian (also called normal) curve that is a classical description of measurement errors. The Gaussian distribution that best fits the data is shown in two different ways in Figure 1C, as a bell-shaped curve (so-called PDF, in blue), which can be compared to the histogram 1B, and a sigmoid-shaped curve (CDF, dotted curve) which has the advantage of being directly comparable to the empirical data (see solid black staircase curve). However, this best fit solution with standard deviation 11 min. is not satisfactory because the difference between the theoretical (dotted) and the empirical (solid) CDFs is too large to result from random fluctuations (see statistical test in legend of Figure 1C). If only the time deviations smaller than 20 min. are taken into account (they include 90% of the values), then the bell curve with standard deviation 6 minutes becomes an acceptable description (see Figure 1D). This result suggests that beside the majority of observers who give time with an error that does not exceed 20 min., there is a minority of people (10%) whose less precise time estimates follow another Gaussian distribution with a much larger standard deviation.

In any case, considering the empirical distribution only, the percentages of witnesses who give the time with a difference of at most (plus or minus) 10, 15 or 30 min are 18, 11 and 4% respectively. We can retain ±30 min as the most relevant since it corresponds to a range of one hour. Let's add a word of caution: it must be realized that we are not actually studying the time estimate of the observers but the time recorded by the investigators and interpreted by the author. Mistakes in recording and interpretation compound with errors made by inaccurate observers.[6]

### Duration

The same method can be applied to the duration of the event, which is given by 71% of witnesses, often as ranges like "10-15 seconds" (we took the mean of the extremes) and sometimes as "a few seconds" (we interpreted as 3 s). Then it appears that the launcher re-entry (#2290), with median duration 35 s, was visible for a much longer time than the meteoroids (all other events), since their median duration is 8 s (range from 3 to 20 s). This is in good agreement with durations found in the literature.[7] Typically, meteors are seen during "a few seconds"[8] or "a fraction of a second to perhaps as long as 10 seconds,"[9] but never more than 4 min 40 s,[10] while satellite re-entries are seen "from maybe 20 seconds to a minute, but these times could be also longer or shorter in duration,"[11] without exceeding 3 min.[12] Thus, the approximately four times longer duration of satellites with respect to meteoroids is sufficient to be perceived by witnesses taken together.

To go further, durations are shown in Figure 2 with the same graphic methods as in Figure 1. Not only the median but also the interquartile range (103 s) is much greater for launcher #2290 than for meteoroids (17 s, range 1-26 s; Figure 2A). The most conspicuous difference with time deviations is apparent in Figure 2B as the histogram is not symmetric, with very short durations being more frequent than longer ones, which means that durations cannot be described by a Gaussian (normal) distribution but requires a skewed distribution. This is shown more precisely in Figure 2C which distinguishes the meteoroids (all six together) and the launcher; we found that the best fit PDF curves computed from the empirical staircases are lognormal distributions.

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[6] For example, in event #1667, the time (19:00) given by two witnesses is ambiguous as it can apply either to the beginning of the dinner or to the meteor sighting. I used the dinner time because in the absence of other independent witnesses, as in most UAP reports, this ambiguity would have been difficult to resolve.

[7] For Hendry (*The UFO Handbook*), duration of meteors "ranges anywhere from one second to as long as twenty seconds" while satellite re-entries "are usually observed for longer than ten seconds" (from 113 reports).

[8] Jeanne, *Méthode d'analyse statistique appliquée au réseau d'observation européen des météores FRIPON.*

[9] Wertheimer, "Perceptual problems."

[10] Alessandri, *Durée des rentrées atmosphériques et des météores*.

[11] Wertheimer, ibid.

[12] Alessandri, ibid.

A variable follows a lognormal distribution if its logarithm follows a normal distribution. This means that while times are measured on an ordinary arithmetic scale (graduated 0, 1, 2, etc. with successive additions) and their central value is given by their arithmetic mean, durations are more adequately measured on a geometric scale (graduated 1, 10, 100, etc. with successive multiplications) and their central value is given by their geometric mean ($n^{\text{th}}$ root of their product) and median which is $\mu^* = 8$ s for meteoroids and 42 s for launcher #2290. As in Figure 1C, where removing the most extreme values improves the fit to a Gaussian distribution, removing the durations greater than 20 s in the meteoroid subset improves the fit to a lognormal distribution with $\mu^* = 5$ s (Figure 2D), suggesting here also that the longest durations obey a law with greater standard deviation.

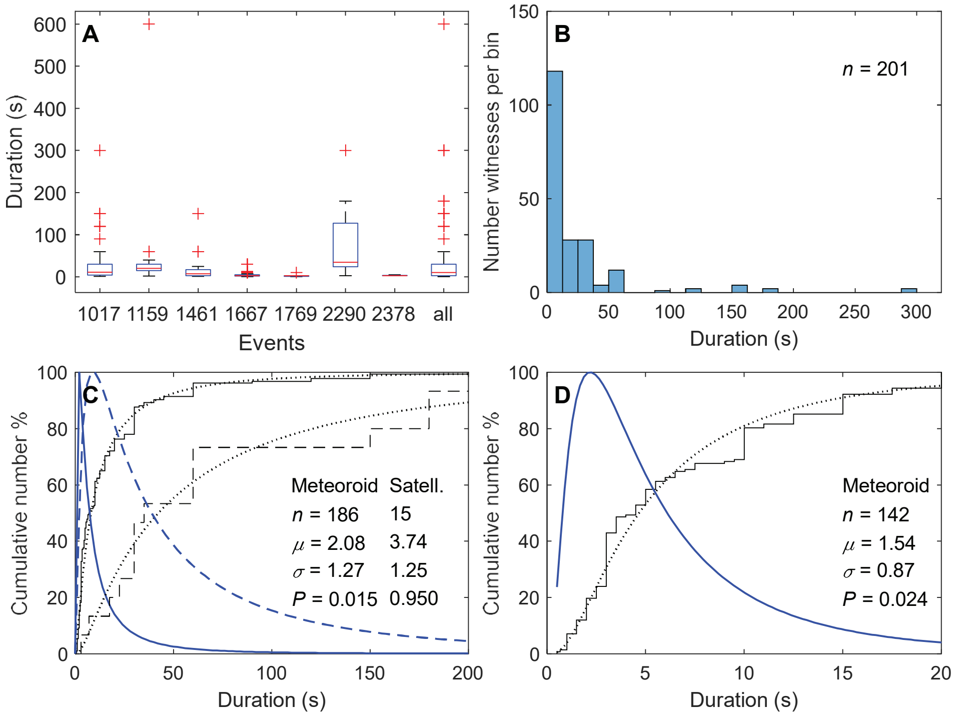

Figure 2. Reported duration of atmospheric entries. **A**. Boxplots of durations for each event and for all events together. Note the wider dispersal of durations for event #2290 (Russian launcher). **B**. Histogram of all durations less than 400 s (regular). **C**. Distribution of regular durations of meteoroids (solid staircase) and launcher #2290 (dashed staircase). **D**. Detailed view of durations less than 20 s for meteoroids (they include 72% of regular durations). Theoretical CDFs in C and D (same line style and color as in Figure 1) are lognormal. Like its Gaussian counterpart, the lognormal distribution is characterized by two parameters, its mean $\mu$ and standard deviation $\sigma$ (see legends inside panels), $\mu^* = \exp(\mu)$ being the median and geometric mean of the lognormal distribution fitted to data. In C, $\mu^* = 8$ s (meteoroids) and 42 s (launcher #2290). In D, $\mu^* = 5$ s (meteoroids).

It follows from the properties of the lognormal distribution and the near equality of standard deviations of meteoroids and satellites (Fig. 2C), that for both types of events, 29% of witnesses give durations greater than or equal to $2\mu^*$, 10% for $5\mu^*$ and 3% for $10\mu^*$. If outliers are defined as in boxplots (see legends of Figure 1A), durations longer than 45 s for meteoroids and 180 s for launcher #2290 are anomalous. This definition is reasonable because it corresponds to durations approximately five times higher than the geometric means $\mu^*$. It yields $n = 26$ outliers for meteoroids and 5 for the launcher, so that 15% of observers can be considered as unreliable with this rule.[13]

**Number of Objects, Fragmentation, and Trail**

The witnesses observed a main object (single or larger than the others; 87%), several objects of equivalent size (7%), a simple trail with no associated object (5%), or did not give a clear indication (2%). In four events (#1159, #1667, #1769, #2378) there is only one object or, if several are seen, one of them is larger than the others. For the 3 other events, the proportion of witnesses who see several similar objects remains low for #1017 (8%) and #2290 (13%) but is clearly higher for #1461 (31%) which is thus the most singular event from this standpoint.

The main object is sometimes accompanied by up to 3 smaller secondary objects during the whole observation (3%) or is reported to break up into up to a dozen fragments (19%), while the main object continues its course. Some observers speak of disintegration or explosion. The frequency of observed disintegrations varies depending on events from about one-third to very few or zero. Presumably, this feature depends on whether the witness' observation starts before the fragmentation of the object takes place or after it. If this interpretation is correct, the observation of a fragmentation should be correlated with the duration of the observation, which is actually the case.[14]

Half of the witnesses described a trail, most often behind the main object (or objects), sometimes alone (5%). The word trail is the most common but sparks, tail, cone, glow, beam, flame, smoke, spray, projection, triangle, comma, light are also found. The proportion of witnesses mentioning a trail is similar across events (it varies in the range 67% to 82%), excepted for meteoroids #1017 and #1461 whose trails were seen by only 27% of observers.

The descriptions of the objects, their fragmentation, and their trails may vary because of actual differences between phenomena, as illustrated by event #1461 for which more objects of similar size were noticed than in the others; or differences in the observation conditions, as suggested by the influence of sighting duration. Without sure norms for judging the truth or error of a witness, reliability is difficult to estimate. However, as with the day and time, we can use surrogate standards by relying on the testimonies. Let's take the example of fragmentations. In 4 events (#1159, #1667, #1769, and #2378; 123 testimonies in all) no fragmentation was described (except by one witness in #1159, which by method we will not take into account). In the three other events about one-third of witnesses (34% for #1017, 35% for #1461, 31% for #2290; 54 witnesses in all) reported a disintegration, which is sufficient evidence that it occurred. Thus, 63% of witnesses correctly reported the presence or absence of a disintegration. The same reasoning applied to trails leads to a reliability of 49%; but in a simpler way, because in all events a trail was mentioned (by

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[13] Drake ("On the abilities and limitations of witnesses of UFO's and similar phenomena") concludes from 113 witness interviews of two bright fireballs in 1962 that "the estimates of duration of the fireball… were remarkably accurate. In these cases, it lasted four seconds, and the estimates were typically between three and five seconds, a remarkedly good performance. The estimates of the length of time until the sonic boom were also about right" (between 1 and 5 min, which is correct within a factor of two).

[14] For short-duration sightings, 16 witnesses reported a fragmentation and 84 none; for long duration, they were 29 and 73 respectively. So, a lesser number of breaking-up is observed during short sightings than in long ones and vice-versa for no breaking up. This correlation is significant with P-value = 0.025 (exact Fisher test).

7 or more witnesses), in accordance with what is expected since all bodies at high speed produce an ionization trail in the atmosphere.

**Colors**

The colors of the main object are indicated by 79% of witnesses. However, this percentage varies across events from 81 to 95% for 4 events and from 41% to 55% for 3 events (#1159, #2290 and #1769). Witnesses utilize a relatively rich vocabulary of 40 terms, including primary (red, green, and blue), secondary (yellow, orange, brown, purple, etc.) and tertiary colors such as "blue-green" etc., a vocabulary further enriched by indications of intensity and saturation. Half of these 40 terms are found in two or more testimonies, and the other half in only one. The colors of the trail differ in several respects from those of the main object: they are less frequently reported (they are mentioned by only 49% of the observers mentioning a trail), and the proportion of trails whose color is indicated varies less across events (in the range 43-64%, except #1461 with 25%). The number of colors mentioned is also smaller (13).

As for several other characteristics, color analysis is hampered by the lack of reference data,[15] since color was briefly reported by a single qualified observer, astronomer Paul Couteau from Nice observatory. He described the trail of meteoroid #1017 as "green and red," "typical of metallic particles heated at very high temperature which detach from the meteorite as a result of friction and burn immediately."[16] Thus, one can only rely on the similarities and differences between color descriptions of the same event. The wide palette of colors suggests that differences outweigh similarities and may confirm the plausibility of Drake's conclusion that "the eye, perhaps especially the dark-adapted eye, when presented with a bright unexpected light, may perceive any color" so that "the colors reported are meaningless."[17]

In order to check this conclusion, we simplified the palette by replacing the tertiary colors by the most frequent primary or secondary color composing them. After reduction, it appears that the most frequently mentioned trail colors for event #1017 are red, green and white (71% of witnesses) in good agreement with Couteau's description. This confirmation may give some weight to the most frequently reduced 'color' we found for the trail, namely white, with two exceptions, #1017 and #1461 (only two witnesses indicate the color of the trail and they disagree: one sees it as red and the other as yellow-green). Interestingly, the white appearance of the trail in most events may explain why so many observers did not report their color, in accordance with the technical notion that white and grey are not colors but shades.

The same procedure applied to the color of the main object (Table 2) shows that the most frequently used terms are green and white (#1017 and #1667), white and yellow (#1461), white and grey (#1159), and white and blue (#1769). For these last two events, their white or grey shade may have contributed to their relatively low percentage of color descriptions (column None). For two events, #2290 (orange and red) and #2378 (orange and green), no white shade was noticed.

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[15] This is a common situation. Drake notes about the two 1962 events he studied "we do not know for sure what color the objects were" ("On the abilities and limitations of witnesses of UFO's and similar phenomena").

[16] Interview in *Dauphiné Libéré*, quoted in Passot, *J'ai vu un OVNI*, p. 20.

[17] Drake, ibid.

So, Drake's conclusions about color vision seem too negative. Indeed, similarities between reports of the same event led to the emergence of dominant colors or shades and to lower reporting frequencies in the case of white and grey shades. Differences are manifested in the variety of terms used which may result from many factors, neural (eye and brain), psychological (attention, memory) and others (reporting).

Table 2. Reduced colors and shades of main object

| Event | None | N | Main colors | n | n% | Other colors | I% |
|---|---|---|---|---|---|---|---|
| 1017 | 6% | 140 | green white red | 115 | 82% | yellow blue orange *dark brown rose* | 18% |
| 1159 | 59% | 15 | white grey blue | 11 | 73% | *dark red* | 27% |
| 1461 | 19% | 25 | white yellow green | 17 | 68% | blue *red* | 32% |
| 1667 | 10% | 69 | green white orange | 50 | 73% | red yellow blue *silver gold black* | 27% |
| 1769 | 45% | 6 | white blue | 4 | 66% | *dark green* | 34% |
| 2290 | 50% | 8 | orange red | 8 | 100% | - | 0% |
| 2378 | 18% | 14 | orange green | 11 | 79% | red *black* | 21% |
| Mean | | | | | 77% | | 23% |

*Event* number. *None*, percentage of witnesses not indicating a color or shade. *N*, total number of terms used by witnesses for describing colors (after reduction) and shades. *Main colors*, two most frequent reduced colors (plus white) indicated by at least 2 witnesses. *n*, total number of colors and shades mentioned in column 'Main colors.' *n%* = n/N in percent. *Other colors*, other terms describing reduced colors and shades (in italics if used by a single witness). *I%* = 100 – n%, percentage of colors and shades mentioned in column 'Other colors.' In columns 'Main colors' and 'Other colors,' colors and shades are ranked by decreasing frequency.

## Altitude

Although altitude is of a wholly different nature from time and duration, let's start by studying it with the same methods as for these variables (Figure 3). The altitude of the phenomenon is given, in meters or kilometers, by only 20% of the observers,[18] a proportion so small that in the two events with the least number of observers (#1769 and #2378, see Table 1), neither of them gave height values. In the five remaining events, two extreme outliers are found (at 125 and 150 km) that are 2 orders of magnitude larger than the values given by the other witnesses (Figure 3A). Once these outliers are removed, we get a clearer view of the data (Figure 3B), showing that both the medians and the IQRs (central rectangles) vary much more between events than in the case of times and durations, which may also result in part from random fluctuations due to the small number of values per event. Nonetheless, the last plot (Figure 3D) shows that the heights of all events together are very well-fitted with a lognormal distribution of median $\mu^* = 300$ m.

Of course, this perceived altitude is definitely wrong. Actually, most meteoroids and artificial satellites burn in the atmosphere at an altitude of between 120 and 80 km.[19, 20, 21] So, the impression of observers is about 300 times smaller than it should be! Clearly, the altitude given by these 20% witnesses has no objective value. For this variable, eyewitness reports are completely unreliable.

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[18] Wertheimer ("Perceptual problems") found in 13 of 30 "relatively complete reports" of Zond IV re-entry that the estimated altitude or distance was less than 20 miles (32 km), which is much more than in our sample (20%).

[19] Jeanne, *Méthode d'analyse statistique appliquée au réseau d'observation européen des météores FRIPON.*

[20] American Meteor Society.

[21] Koten et al., "Atmospheric trajectories and light curves of shower meteors."

Should we be surprised? Not really, because the altitude and distance of an object seen in the sky cannot be determined without prior knowledge of its size or nature.[22] Only *angular* height and size can be determined. Unfortunately, this simple rule does not seem to be known by most observers and investigators (only 4% witnesses gave height in degrees). The only two observers who gave a correct altitude are the astronomer Jean Couteau (150 km, event #1017) and a pilot in flight (125 km, event #1667), surely (for the astronomer) or probably (for the pilot) because of their scientific knowledge of meteoroids. The two other large values (25 and 12 km, in event #1159) were possibly influenced by what the observers knew about the altitude of airliners. Except for those 4 cases and possibly 9 others where the object was felt as "high" (4%), most observers judged that its height was less than 5 km or "low" (32%).

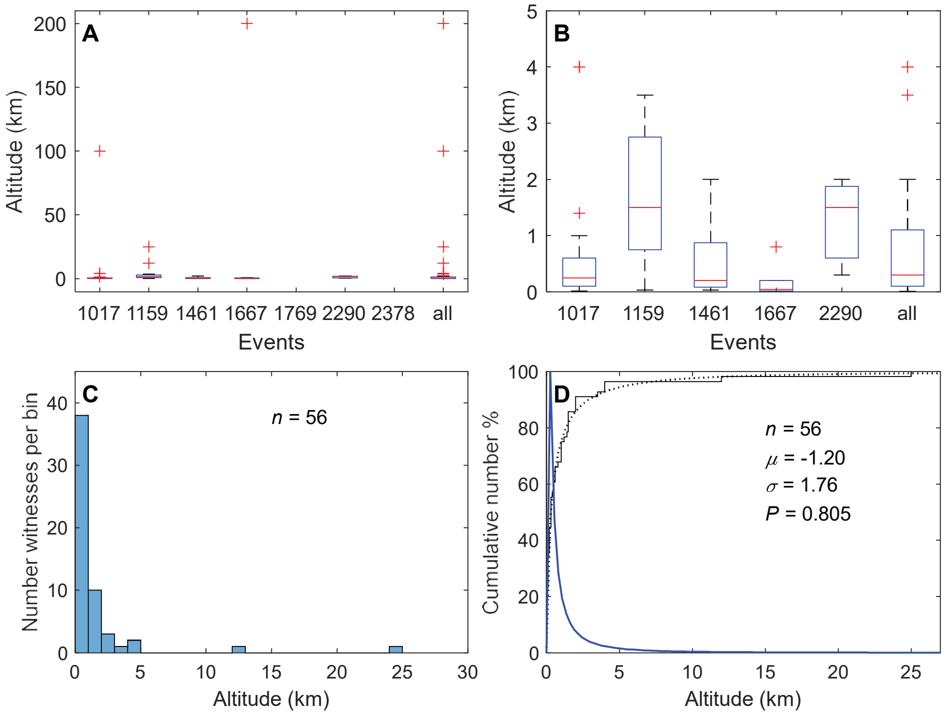

Figure 3. Subjective estimates of altitude of atmospheric entries. **A**. Boxplot of altitudes for 5 events (no estimate for 2 events, #1769 and #2378) and for all 5 events together. **B**. Same as A for altitudes below 30 km with view restricted to 0-5 km (two outliers in event #1159 are not shown). **C**. Histogram of altitudes. **D**. Distribution of altitudes less than 30 km; same representation as in Figure 2 with lognormal CDF and PDF. Lognormal fit not rejected at level 5% (P-value = 0.8).

However, human perception is not as fallible as the previous results may suggest because not only do many eyewitnesses express doubts on their ability to estimate the height, but, more significantly, the majority of them (56%) do not provide any indication about height, even qualitative (like "high" or "low"), which is much more than for time (6%) and duration (29%). This wariness might reflect a widely shared feeling that determining height was not possible under their conditions of observation.

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[22] As stated by Wertheimer ("Perceptual problems"): "an unknown, vaguely defined object in the undifferentiated sky can appear to be of any size or at any distance, depending on the inferences made by the observer."

### Distance

The distance of the phenomenon is given quantitatively (in meters or kilometers, 14%) or qualitatively (“near” or “far,” 2.5% each) by a minority of witnesses, whereas the majority prefers to abstain from any indication (81%). So, witnesses are even more reluctant to give a distance than an altitude. However, for those who dare to provide a quantitative value, the results are very similar for distance and altitude (Fig 4), although only 18 people give both values. Most entries are felt to take place at less than 5 km (Figures 4A and 4B). Distances follow a lognormal distribution with a median distance of about 650 m (Figure 4C) which is practically identical to the distribution of altitudes (Figure 4D).

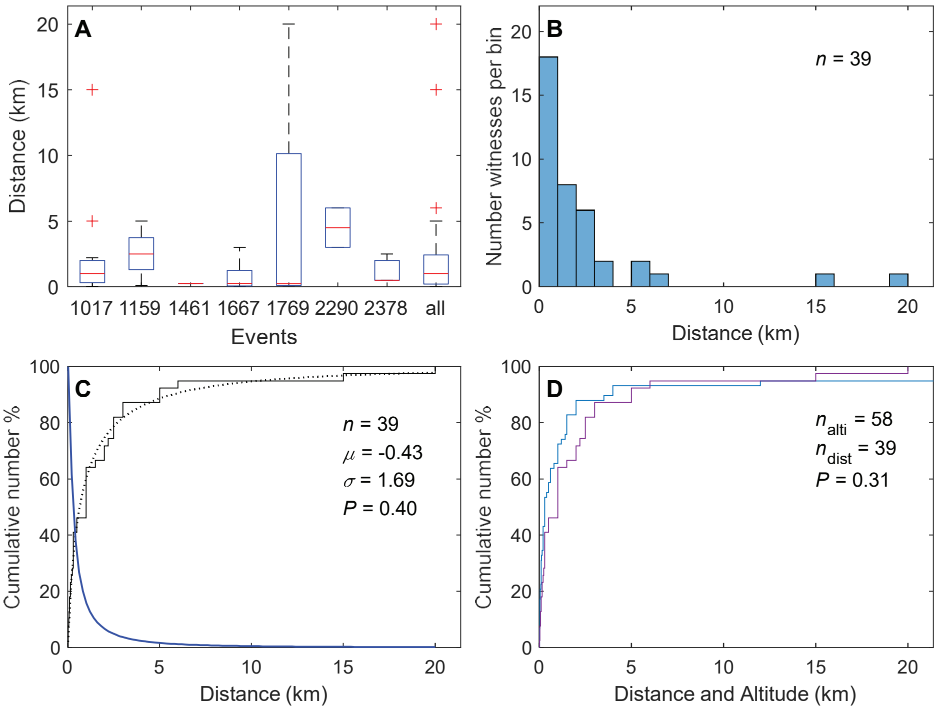

Figure 4. Subjective distance of atmospheric entries. Same representation as in Figure 3. **A**. Boxplot of distances per events and for all 7 events together. **B**. Histogram of distances. **C**. Distribution of distances fitted to a lognormal distribution (not rejected at level 5%, P = 0.40), same representation as in Figure 2. **D**. Comparison of cumulative distributions of distances (purple staircase) and altitudes less than 100 km (blue); null hypothesis (altitude and distance are drawn from the same underlying continuous population) cannot be rejected at the 5% level (P-value = 0.31).

This near identity is in blatant contradiction with reality, because distance is typically greater than altitude in atmospheric entries. A meteoroid entering the Earth atmosphere just above an observer (height 90°) is at the shortest possible distance (about 100 km). At the other extreme, a meteoroid entering the atmosphere close to the horizon (height 0°) is at the maximum possible distance because the curvature of the Earth limits the horizontal distance at which it can be seen before it becomes invisible below the horizon. An elementary geometrical calculation shows that the maximum distance is approximately in the range 1000-1200 km. Thus, distance can be up to about one order of magnitude greater than altitude, depending on the height of the meteoroid above the horizon. As a result, the discrepancy between the distance reported by the most naïve observers and the actual distance is still greater than for the altitude.

The near identity of perceived distance and perceived altitude is consistent with the idea that both perceptions result from similar unconscious processing, possibly based on experiences gained with lights seen at closer distance. Extrapolating from these ordinary experiences shared by all observers leads to wrong estimates in the case of powerful faraway lights as seen in atmospheric entries.

## Direction of Motion

The majority of observers report the apparent direction followed by the object (71%). However, this indication may be given ambiguously (like NE-SE or E-SW; 7%), incompletely (e.g. to the S; 5%) or with respect to geographical landmarks (7%; we have not analyzed these indications). Finally, direction is given clearly by 52% of witnesses, mostly with respect to the four cardinal directions (e.g. N-S, etc.), less frequently with respect to the intermediate directions (NE-SW, SE-NW, etc.) and rarely using the other subdivisions of the compass rose (only 4 occurrences, all NNW-SSE). At first sight, the directions reported seem very messy. For example, in the event #1017 reported by 117 people, one finds 58 regular directions, namely 27 N-S, 19 E-W, 12 NE-SW, plus 3 other directions each given by a single witness. Other directions are ambiguous (E-SW, ENE-SSW, NW-SSE) or in contradiction with the regular ones, either opposite (S-N, SW-NE) or perpendicular (SE-NW, SE-NW then S). It is tempting to conclude that data as diverse and contradictory as those are unusable and to reject them as a whole. However, this quick conclusion is not warranted.

Indeed, let’s consider the case of an object moving in a plane almost perpendicular to the vertical of the witness, which is consistent with the horizontal trajectories often reported. This witness can determine the object direction if and only if it passes overhead (as reported for case #1017 by a witness in Corsica). If this condition is not met and if we assume that he/she cannot appreciate any variation in distance, the direction of motion cannot be determined. Then the trajectory appears as an almost horizontal line in the observer viewing direction (this line is the projection of the real trajectory on the vertical plane perpendicular to the viewing direction). Then, the only things the witness can actually observe are the viewing direction and the object motion to the right or left. Whatever the heading of the object (except for a trajectory oriented towards the witness), if he/she is looking towards the North (or the South), the object will be seen as moving from East to West (or vice versa), if he/she looks westward (or eastward), he/she will judge that it is moving from North to South (or vice versa), etc. The generalization to other viewing directions is straightforward. So, for a distant object flying NW-SE, it may happen that some say N-S (they look E), others W-E (they look N), still others NW-SE (they look NE). Contrary to appearances, these directions do not necessarily contradict one another. Witnesses would only contradict if some described trajectories oriented S-N, E-W or SW-NE, i.e. an object travelling in the opposite direction.

With this narrower definition of what can be considered as an inconsistency in the reported directions, we can analyze the available data of each event. Here again we only consider the directions given by at least two observers. Table 3 shows that besides a few ambiguous directions, inconsistent directions are found only for event #1667 with 3 witnesses reporting an East-West movement, which contradicts all other 30 reports. This small number of inconsistencies (3/137 = 2% of analyzed directions) is surprising because we expected that many witnesses would not be able to correctly identify the cardinal directions, especially far from home. The available data do not confirm this expectation.[23] However, the consistency criterion utilized is relatively imprecise (±45°), so that the small percentage found might be a mere consequence of this tolerance to orientation errors.

Table 3. Main directions of motion reported and corresponding number of witnesses

| Event | n | None | Geo | Inc | Amb | Uni | Main regular directions | | | | | Sum |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1017 | 117 | 34 | 16 | 2 | 4 | 3 | N-S:27 | E-W:19 | NE-SW:12 | | | 58 |
| 1159 | 35 | 17 | 0 | 3 | 3 | 1 | S-N:5 | SW-NE:3 | W-E:3 | | | 11 |
| 1461 | 26 | 3 | 0 | 0 | 6 | 2 | S-N:8 | SE-NW:5 | E-W:2 | | | 15 |
| 1667 | 64 | 14 | 4 | 6 | 5 | 2 | N-S:13 | W-E:10 | NW-SE:5 | ***E-W:3*** | NNW-SSE:2 | 33 |
| 1769 | 11 | 3 | 0 | 0 | 0 | 1 | N-S:7 | | | | | 7 |
| 2290 | 16 | 3 | 0 | 0 | 0 | 2 | N-S:6 | W-E:3 | NNW-SSE:2 | | | 11 |
| 2378 | 14 | 7 | 0 | 2 | 2 | 1 | N-S:2 | | | | | 2 |

*Event* number. *n*, number of witnesses. *None*, no direction reported. *Geo*, geographical landmarks (not analyzed). *Inc*, incomplete directions. *Amb*, ambiguous directions. *Uni*, number of directions indicated by only one witness. *Directions*, main regular directions mentioned by at least 2 witnesses (in descending order of number of witnesses). *Sum*, number of witnesses in columns 'Main directions' (137 witnesses in all). Inconsistent direction in bold italics (E-W in #1667).

## Interpretation of Observed Phenomena by Witnesses

The two most common interpretations of their sighting by witnesses are "UFO" (*ovni*) and "meteor or spatial debris," although other interpretations are also given (optical effect, plane on fire, tractor with flashing beacon) but only in a few reports. The word *ovni* is found in 17 testimonies (6%). Adding descriptive terms like *hublots* (portholes) and *engin* (craft), about 11% of witnesses evoke an artificial machine. The words "meteor," "meteorite," "bolide," "body in the atmosphere," "atmospheric entry" appear in 25 reports (9%, I have removed from this count the witnesses who think they have *not* seen a meteor).[24] In three cases the witness considered both hypotheses and did not choose. In most reports no interpretation is given.

Does the witness's interpretation influence the reported characteristics of the object or vice-versa? This idea can be tested by crossing the witness's interpretation (meteor or machine) with the distance or altitude of the object (estimated numerically or not) assuming that the witnesses who give an estimate are more prone to the illusion that the objects are close. For altitude, Table 4 shows a slight relationship that is in line with this expectation, since those who interpret the phenomenon as a strange flying craft give an altitude (much too low as we have seen) a little more frequently than those who see a meteor.[25] It means that the impression of proximity felt by

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[23] In his doctoral thesis (*Témoignage d'ovni et psychologie de la perception*) Jimenez notes that the reported directions are "often adequate," but without further explanation.

[24] Wertheimer ("Perceptual problems") found 12 reports suggesting meteor(ite) or satellite in his sample of "relatively complete" reports (i.e. 40% of the sample).

[25] This apparent relationship is not statistically significant, and thus might result from a mere random fluctuation. Likewise, the table "interpretation vs. distance" displays no significant relationship (P-value = 0.68, Fisher test). However, Jimenez (*Témoignage d'ovni et psychologie de la perception*) found a significant dependence in a contingency table crossing 4 distances (unreported or far, above the horizon, below the horizon, metric) and 6 descriptive terms (light, phenomenon, object, craft, flying object) and in a factorial correspondence analysis, a statistical method that makes use of many characteristics at once (see also his book *La psychologie de la perception*). In addition to the modalities used, including the absence of the term "meteor" in his list of denominations, a major

witnesses influences their interpretation to some extent, although it does not really determine it. It suggests that for the majority of witnesses (21 of 32 to 20 of 25) the high-level processes (interpretative) are not dominated by the low-level ones (sensory).

Table 4. Cross-tabulation of witness' interpretation and altitude

| | | Altitude | | |
|---|---|---|---|---|
| | | Metric | Not metric | Sum |
| Interpretation | Meteor | 5 (7.0) | 20 (18.0) | 25 |
| | Machine | 11 (9.0) | 21 (23.0) | 32 |
| | Sum | 16 | 41 | 57 |

Number of witnesses interpreting the observed object as a meteor (with altitude estimated numerically or not) and as a machine (idem). Numbers in parentheses (products of the marginal sums divided by grand total n = 57) are expected if both variables are independent. Null-hypothesis (independence of variables) not rejected at level 5% (P-value = 0.18, Fisher exact test).

Another question is: How many witnesses were deceived to the point of believing that they experienced a close encounter with a UFO? Considering encounters as close when made at 300 m or less, our sample includes 16 sightings (6%) of this kind (of which 3 are at 50 m or less), plus 7 sightings (2%) judged "close" without further clarification. The most remarkable testimony of this subset comes from a witness who was a nine-year-old boy when he saw the meteoroid #1017 in 1980. Here are some excerpts of his report sent to GEIPAN in 2011:

> *We saw an oval, stationary, very luminous object at less than thirty meters, at about twenty meters above one of the fields. The object flew silently and was illuminated with changing colors, from green to orange. I was so frightened that I lay down between the seats of our Renault 16.... The object slowly moved vertically, then sped southwards... at a speed that could be interpreted as a simple 'disappearance.' During this lightning acceleration, three white luminous balls escaped from the object and followed it at the same speed.… My natural interpretation was that visitors from outer space had landed near the house, and that this had to mean something.… Having informed myself about the technical possibilities of such a* [*supersonic*] *aircraft in 1980…, it seems to me reasonable to think that its origin was extraterrestrial.*

In addition to the false impression of proximity, the object's movement (stationary, then slow vertical displacement and lightning acceleration) and observation time (1-2 minutes) are distorted. The rest of the description is in good agreement with those of other witnesses, including the three balls behind the main object that were mentioned several times, and leaves no doubt about the meteoroid identification. It is noteworthy that the reconstructions provided by the witness show the phenomenon against the sky background. The young age of the witness and his fear may have contributed to his wrong interpretations.

The two other sightings at short distance (20 and 30 m) are less interesting because, as an exception to the rule, the police report gives no verbatim accounts from the witnesses but only a sketchy summary. The few characteristics given are consistent with the fireball #1667 except for the distance. The fourth sighting (at 60-70 m, #1017) is also exceptional because the witness saw an

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difference with our study is Jimenez' inclusion of the spectacular re-entry of a Proton launcher on November 5, 1990, which alone generated over 500 police reports. See Reference #4.

object apparently motionless, but he was driving at 40 km/h. None of the other sightings felt at close range present any “eccentric” element, except for the use of the expression “it looked like a flying saucer” (#1159).

In summary, in 21 of the alleged 23 close encounters, only the distance given is clearly wrong, the other descriptive items being consistent with an atmospheric entry. The frequency of eccentric testimonies is therefore 2/23 (9%) or 2/283 (0.7%, where 283 is the number of testimonies studied) according to the chosen reference.[26]

## The Many Facets of Reliability

Are witnesses reliable? A yes or no answer to this question would certainly be unwarranted, and even trying to capture witness reliability with a single measure without further caveats would be equally misleading, as reliability varies between practically 0 and 100% depending on the characteristics considered. For the 12 spatial, temporal and structural characteristics we have studied, reliability is primarily affected by three factors.

The first factor concerns whether an observer can actually know a given characteristic based on the sensory data (column “Access” in Table 5). The spatial characteristics (altitude, distance, size, speed) cannot be known directly except in special circumstances, such as with an object of known size, or passing in front of a background at known distance, or seen from two places sufficiently distant to allow a triangulation, or close enough for binocular vision to operate.[27] The direction of motion is reliable only if the object passes vertically over the witness. Apart from these special cases, the witness reliability for the absolute spatial characteristics is a priori null. This is not a question of reliability as such but of principle. Thus, asking a witness the height, distance, size (in meters) or heading of an unknown object in the sky has hardly more sense than asking him its chemical composition or its country of origin (if any). What is at stake here is not the reliability of the observer but of the investigator or analyst.

In contrast, most other characteristics, like viewing directions, date and time, duration, aspect, and colors, are directly accessible, at least in principle. Nonetheless, they differ in how one decides whether a witness statement is true or false or how much it deviates from reality (column “Norm” in Table 5). We know, for example, that atmospheric entries are visible at altitudes between about 80 and 120 km and that their duration is less than about 20 s (meteoroids) or 60 s (artificial satellites). Even though they are rough, these values are useful references for our purpose. All other characteristics – date, time, directions of observation, colors – vary from event to event. No constant references being available, norms must be established for each event based on instrumental records, expert accounts, or some form of averaging procedure (best illustrated here by the times given by witnesses which apparently peak around the actual time of the event). In practice, we used 3 types of norms (column “Criterion” in Table 5): (i) partly arbitrary thresholds beyond which the witness is assumed to be in error (date, time, duration); (ii) norms fixed by the

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[26] Menzel (“UFOs—The Modern Myth”) gives 3 examples of eccentric testimonies following the re-entry of satellite Zond IV on March 3, 1968. He only states that “hundreds of people made detailed reports of their sightings.” Hartmann (“Process of Perception, Conception, and Reporting”) for the same event mentions 78 records. Thus, the eccentricity ratio would be between 1% (if we assume 300 records) and 4%.

[27] Readers interested in distance perception should refer to chapter 4 of *Témoignage d’ovni et psychologie de la perception*, where Jimenez reviews the literature on this subject. See also Maugé’s chapter in this volume.

method itself (motion, trail); and (iii) norms derived from the majority (or unanimity) of witnesses (fragmentation, colors, apparent heading). The reliability of accessible characteristics ranges from 49% to 98%, the qualitative characteristics being less reliable on average than the quantitative ones (Table 5).

A third factor plays an important role: the number of testimonies providing data about a given characteristic. As shown in column "Responses" of Table 5, it varies from 14% to 100% for the characteristics studied. Characteristics with lower frequencies would be more difficult to study. Obviously, this frequency depends on the witnesses but also on the investigators and reminds us that the quality of the investigations could be improved, particularly for angular and distance data.

Table 5. Overview of factors involved in witness reliability for 12 characteristics

| Characteristic | Scale | Access | Norm | Type | Resp. | Reli. | Criterion |
|---|---|---|---|---|---|---|---|
| Distance | quan | no | no | zero | 14% | 0% | - |
| Altitude | quan | no | yes | zero | 20% | 1% | - or >40 km |
| Heading | quan | no | no | zero | 52% | - | - |
| Trail | logi | yes | yes | intrinsic | 49% | 49% | always present |
| Fragmentation | logi | yes | consistency | majority | 98% | 63% | majority |
| Color object | qual | yes | consistency | majority | 79% | 77% | majority |
| Color trail | qual | yes | consistency | majority | 27% | 80% | majority |
| Duration | quan | yes | yes+mean | threshold | 71% | 85% | ≤5 median (µ*) |
| Time | quan | yes | mean | threshold | 94% | 96% | ≤30 min |
| Date | quan | yes | mean | threshold | 100% | 98% | ≤1 day |
| Motion object | logi | yes | yes | intrinsic | 51% | 98% | always moving |
| Apparent heading | quan | yes | consistency | majority | 48% | 98% | majority |

*Characteristics* studied ranked by increasing reliability and classified in 3 groups (non-accessible, accessible qualitative and accessible quantitative). *Scale*, measurement scale of the characteristic: logical (true/false), quantitative (quan) or qualitative (qual). *Access*, characteristic directly accessible to witnesses (at least in principle) or not. *Norm*, the true value of the characteristics cannot be known by the analyst (no) or can be known approximately from the literature on atmospheric entries (yes) or from all witnesses of the same event (based on mean or internal consistency). *Reliability type*, in four categories: zero a priori, given with respect to a threshold, intrinsic to the method proposed, or based on the majority of witnesses. *Response*, percentage of witnesses providing information on the characteristic. *Reliability*: number of correct responses (according to the specified *Criterion*) out of total number of responses (non-responses excluded, except for Trail), expressed in percent.

Based on these three factors (access, norms and report frequencies), the reliability of a characteristic is measured by the number of correct responses (according to some specified criterion) out of the total number of responses, expressed in percent. This reliability measure mainly reflects the perceptual and cognitive performance of the observers but inevitably includes a component related to the investigators and analysts.

### Events with a Single Witness or Only a Few Witnesses

Can these results be applied to events of unknown origin with only one or a few witnesses, which are the most frequent in UAP archives? If the reliability estimates of various characteristics expressed in percent in Table 5 do not depend too closely on the specifics of atmospheric entries, they should be applicable to the same or comparable characteristics in single-witness events, at least as a first approximation. They indicate what would happen if the observation could be repeated with several witnesses instead of a single one.

## Conclusions

Witness reliability is not a simple concept, as it is highly dependent on the characteristics studied, the methods used, and the expected accuracy of the results.

(i) As for all characteristics, the reliability of time indications decreases with their precision. The less precise indication, date, is exact for 98% of witnesses; followed by time with 96% of time estimates given with an error not exceeding 30 min and 82% not exceeding 10 min. Duration is much more demanding; usually purely subjective, it apparently tends to be overestimated, and can exceed 5 times the true duration for 15% of witnesses due to the long tail of its lognormal distribution.

(ii) Indications of height and distance are grossly underestimated and are of no value unless they are corroborated with respect to an element of the environment at known or knowable distance. Investigators could greatly improve these indications by helping witnesses provide objective information (e.g., angular data instead of metric data) and by using non-verbal methods to measure them.[28]

(iii) Reported trajectories are unreliable but seem to be convertible into sighting directions, albeit with a rather large uncertainty of ±45°. For azimuths, as for angular heights and other characteristics, much better measurements could be obtained by using non-verbal methods, which again shows that reliability is not a static notion but depends on the methods of investigation.

(iv) The qualitative details relative to structure and colors of objects (like presence of fragments or a trail) depend in a complex way on their intrinsic visibility, and the observational skills and sensory limitations of the witness. Obviously, many details, as shown by the example of the trail, will not be described even when present. Other details, more frequently reported like the colors of the main object, seem consistent across up to about 75% of witnesses; it means that the probability for a witness to correctly report the main colors of a phenomenon is about 0.75, or equivalently that 1/4th of hypothetical witnesses of the same event would report different colors.

(v) The reliability of the qualitative characteristics (colors, tail, fragments), which varies between 50% and 80%, appears to be lower than the reliability of the accessible quantitative characteristics (duration, time, date, movement) which is between 80 and 98% with the chosen criteria.

Although there is considerable room for improvement in previous analyses, this five-point summary based on a sample of atmospheric entries of meteoroids and satellites provides useful guidelines for assessing other types of UAP events. However, further studies are needed to better understand differences with previous studies and to estimate reliabilities of other events of longer duration, at shorter distance, involving objects of different structure and light intensity, and with witnesses from other countries, times and states of mind (for example: frightened).

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[28] I give examples of such methods in Reference #14. Non-verbal methods are also advocated by Shepard ("Some psychologically oriented techniques for the scientific investigation of unidentified aerial phenomena.")

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